This great basin should in twenty years become the granary of the world.

The effects of irrigation will be permanently advantageous, because, when the soil once becomes moistened it will subsequently require the application of less water for each crop, and when once a thorough and comprehensive system is adopted the waters could readily be applied, if necessary, before the first rains to soften the ground and make it fit for the plow.

In fact, the whole method and season of cultivation would doubtless be modified, and it is within the range of probability to look forward to an average of two crops a year.

In the development of the irrigation of the vàlley another favorable feature would naturally be added in the cultivation of trees. These would not only be a remunerative source of investment, but would have a beneficial influence upon the soil and upon the young crops, because, if in sufficient bodies and numbers, they would protect the crops from the strong cold northers which have been mentioned as blighting the young and tender grain; and they would in a measure prevent the excessive rate of evaporation which now prevails during the hot summer-months in this comparatively treeless valley.

CHAPTER III.

1. Necessity of surveys--The funds at the disposal of the commission would not authorize surveys--Necessity of an instrumental reconnaissance and of detailed surveys.
2. System of irrigation--No continuous canal on the eastern side of the Great Valley--Each river may have one or more dams and canals--The San Joaquin and King's River Canal--Other canals--Some portion of the plain cannot be thoroughly irrigated--Canals on the western side of the Sacramento River--Main canal may be navigable--Clear Lake and its contents.
3. Influence of irrigation on the navigation of rivers--This influence is small--Experience in Italy and in India--Argument to show that this influence will be small on the navigation of the Sacramento and San Joaquin Rivers--Compensation by making some canals navigable.
4. What is irrigation?--Mistakes that have been made--Description as to how water is to be taken from a river and distributed over the land by dams, head-works, and canals--Examples taken from the San Joaquin and King's River Canal Company.
5. Existing and hypothetical canals--Existing canals at Bakersfield and Visalia--Canals from the King's River--The Chapman Canal--The Fresno Canal--Small canals--Hypothetical canals shown on the map.

6. General considerations--Necessity of proper plans and location of works--Necessity of some authority--Farmers alone will never project and execute a comprehensive system--Connection between the irrigation of the foot-hills and mining and reclamation--Duty of Government.

NECESSITY OF SURVEYS.

We remark that it was evident to us from the moment we commenced our examination of the Great Valley that it would be entirely impossible for us, on account of the limited time at our command, as well as the limited means at our disposal, to enter into details as regards the many problems in engineering which must present themselves for solution before a full report on the best system of irrigating these valleys could be perfected.

Such a report, as well as the first legislation on the subject of irrigating the Great Valley, should be founded on a careful instrumental reconnaissance, to embrace all the streams, and determine where a dam or dams on each of them can be best located; the amount of water that may be utilized; and the lines of main irrigating-canals. This would enable the valley to be divided into districts, and determine the amount of land that may be irrigated in each.

After such reconnaissances shall have established the extent and resources of the natural districts into which the valley is divided, then, when works of irrigation are contemplated in any given district, a minute survey should be made of that district, to determine the detailed location of the main canals and distributing-ditches.

The first reconnaissance specified could be made of a reasonable outlay, but the subsequent minute surveys, embracing specifications, plans, and estimates of the cost of works, will require a large expenditure.

It is not necessary, however, that the proposed instrumental reconnaissance shall be undertaken and carried through the entire valley at once, because the different districts are somewhat independent of each other, and are not in the same immediate need of irrigation.

THE SYSTEM OF IRRIGATION.

We see from the topographical features of the eastern slope of the Great Valley that although water for irrigation is abundant, yet there cannot be any long line of continuous canal on that side, because all the rivers named above, and many smaller streams, flow down from the Sierra Nevada Mountains, and enter the plains in a direction more or less perpendicular to the Sacramento and San Joaquin Rivers, into which nearly all of these rivers finally empty.

No continuous canal can, therefore, be built, without great cost, along the foot-hills on the east side of the valley, because such a canal would cross the rivers escaping from the Sierra Nevada Mountains generally at right angles. The expense of bridging these streams with aqueducts or siphons to carry an irrigating-canal, in this country, with the present price of labor and material, would be enormous.

The system of irrigation on the eastern side of the Great Valley must, therefore, be by many short canals, so as to avoid crossing the different rivers and smaller streams by aqueducts.

Each river may have one or more dams thrown across it in the most favorable places.

All other considerations being the same, the higher up the streams the dams are placed the better, because it will always be desirable that the location and plan of the canals should be adapted to the irrigation of the largest area practicable at reasonable cost; and, besides, by keeping the canals which draw their supplies of water from the main rivers on a higher level, we will be enabled to draw from them to supply those canals which are fed from the smaller streams, such as the Fresno, Chowchilla, Calaveras, Cosumnes, and Bear Rivers, as well as many others still smaller, which do not head in the high mountains, and whose water will, therefore, fail in the dry season. These dams across the larger rivers, as a general thing, will not be for the purpose of storing the river-water, however desirable such storage might be, but for the purpose of raising the surface of the water to such a height as will enable it to be carried out over or through the banks of the rivers, and get the canals into the plains which are to be irrigated at the least possible expense.

Each main river on the eastern side of the valley may thus have two canals, one on its right bank, the other on the left bank, and these main canals may be carried along on the proper grade so as to intersect the similar canals of the adjacent rivers to the right and left, supplying water, also, where it is wanted and where it can be made available to those smaller canals on a lower level which draw their supplies from the streams that do not head high enough in the mountains to have a perennial supply.

The proper location of the dams across the main rivers, and of the head-works and alignment of the main exterior canals, will present the most difficult and important problem which the hydraulic engineer undertaking the irrigation of the eastern side of the Great Valley will have to solve.

The dividing-line between a cost too great, in order to embrace more land, and the sacrifice of land that should be irrigated, will often have to be carefully determined by financial considerations.

It may be remarked that the banks of the rivers as well as of the smaller streams, as they flow through the lower plains, are, in many cases, higher than the plains to the right and left. The increased elevation of the banks of the rivers and creeks is usually discernible by the naked eye; but where instrumental levels have been taken the increased height of the banks, in some cases, appears to be very marked. Thus, on the Sacramento River, a few miles south of Colusa, the bank on the west side of the river was found by accurate levels to be twenty-one feet higher than the land at a distance of two and a half miles westward from the river. On the lower parts of the plains, where the river-banks are higher than the adjacent country, it will be necessary to carry the primary or secondary canals along on these banks in order that the adjacent plains may be irrigated.

It being impossible for us, on account of the limited time and means at our command, to enter upon such a minute reconnaissance of the Great Valley as must be made before a comprehensive and economical system of irrigation can be planned, we have availed ourselves of all attainable information bearing on the subject of irrigation of the valleys mentioned in the act of Congress.

The information thus obtained, mostly from surveys for proposed canals and from railroad-surveys, together with our own observations while traveling through and examining the country, furnish much of the data for this report.

Fortunately, our information about the west side of the San Joaquin and Sacramento Valleys is quite full, and is sufficient to enable us to lay down, with tolerable accuracy, the alignment, size, and slope of the main canals on that side of the Great Valley.

The San Joaquin and King's River Canal and Irrigating Company have already built a canal for irrigation from the great bend in the San Joaquin River (a few miles below Watson's Ferry) to Los Banos Creek, a distance of forty miles, and that company have caused an extensive system of experimental surveys to be made on the west side of the San Joaquin River, all the way from near the mouth of that river, to and around Kern Lake, to Kern River.

These surveys were made with the view of extending their present canal and also of ascertaining the practicability of constructing other canals on a higher level, drawing their supply of water from Tulare Lake and Kern River.

The company having kindly placed all the data in their office at our disposal, we are enabled to lay down the alignment of the canals for irrigation on the west side of the San Joaquin Valley.

These canals are:

1st. The canal already built from the great bend of the San Joaquin River to Los Banos Creek, a distance of forty miles. It is 28 feet wide on the bottom, is 6 feet deep, has a sectional area, when full, of 276 square feet, and with a grade of 1 foot per mile. The canal, when full, will therefore deliver 726 cubic feet of water per second, which would irrigate one hundred and forty-five thousand acres of ~~land,~~ allowing 1 cubic foot of water per second for two hundred acres.

2d. The proposed continuation of this canal, on a grade of 6 inches to the mile, to the Lower San Joaquin River, near Moore's landing.[15]

3d. A proposed canal from Summit Lake,[16] but actually drawing its supply of water from Tulare Lake, (which is fed by King's, Kaweah, Tule, and Kern Rivers,) and extending from Summit Lake to the Lower San Joaquin River at Antioch.[17] This canal is laid down from actual surveys made by the company and is on a grade of 6 inches per mile.

4th. A proposed canal carried from Kern River, on a grade of 3 inches to the mile, beginning on the left bank of that river above Bakersfield and extending around and to the southward of Kern and Buena Vista Lakes. This canal would irrigate the country between it and Kern River and those lakes.

Here we may properly remark that the plain to the east and south of this latter canal, lying between it and the surrounding foot-hills, does not seem to be capable of irrigation, because it is higher than the proposed canal, even with its small grade.

Doubtless, some irrigation of portions of this plain can be effected by storing the water which now escapes through the small streams from the surrounding mountains during the winter-season. It may be possible, too, in the distant future, when the country becomes rich enough to stand the expense, to irrigate all of this land by taking the water out of Kern River high enough up that river to enable it to flow over the entire plain, but the expense of such a construction would be too great for many years to come.

The same remarks apply to the extensive plains southwest and northwest of Tulare Lake, between that lake and the line of the upper canal, (leading to Antioch,) and the foot-hills of the Coast Range. Except partial irrigation of small portions of these plains by storage-reservoirs, they must be considered as non-irrigable; for there is no large supply of water on this side of the valley that can be spread over them, and water cannot be brought from the large rivers on the eastern side of the valley except at a cost which would be disproportionate to the benefits to be derived from such enterprises.

We also have a very good preliminary survey of the alignment of a canal for irrigation and navigation on the west side of the Sacramento River, leading from a point just below Red Bluff to the navigable waters of Cache Slough. This survey was made under the auspices and by authority of the State of California in 1866.

We have laid down on our map the route of this canal as projected by its engineers. It leaves the Sacramento River just below Red Bluff, keeps close to the foot-hills, so as to irrigate all the lands below it, and finally terminates at the head of navigation at Cache Slough.

The quantity of land to be irrigated by this canal was estimated to be 782,000 acres, and the quantity of water necessary for the irrigation of this land and for navigation was supposed to be 6,571 cubic feet per second. This canal was projected for navigation as well as irrigation. In view of this fact, we think if a canal for irrigation alone were to be built here, important changes in the location, size, and slope of such canal could be made, whereby the cost would be greatly reduced.

But even if this canal be made for navigation, which it probably ought to be, its size may be greatly reduced if Stony, Cache, and Puta Creeks be used as feeders, which was not done in the original project.

A branch-canal leaves this main canal on the right bank of Stony Creek, and extends thence to the Sacramento River, and then down on the right bank of the river to Knight's landing, for the purpose of irrigating the land between the river-bank and the "trough," or lowest depression of the valley between the river and the foot-hills to the westward.

A private corporation, the Clear Lake Water-Works Company, has undertaken the appropriation of the waters of Cache Creek for purpose of irrigation.

A canal is now partially completed for the irrigation of sixteen thousand acres of land in Capay Valley, and a dam has been constructed at the lower end of this valley for the purpose of starting two canals, one on either side of Cache Creek, for the irrigation of the plains in Solano and Yolo Counties.

Clear Lake, which is drained by Cache Creek, is a fine natural reservoir, covering about eighty square miles; and as its drainage-area, together with that of Cache Creek, is one thousand square miles in extent, and as most of the water can be stored in the lake by inexpensive works, when it is not wanted for irrigation it follows that a large body of land, probably four hundred thousand acres, can be irrigated by the proposed canals, which are to draw their supply of water from Cache Creek. This company has also kindly placed at our disposal all the information which their plans and surveys furnish, and we have laid down their finished canal as well as their proposed canals on our map.

THE INFLUENCE OF IRRIGATION ON THE NAVIGATION OF RIVERS.

It has been supposed by some persons that the withdrawal of large quantities of water from the Sacramento and San Joaquin Rivers, and from their tributaries, and the appropriation of these waters to purposes of irrigation, would be inconsistent with the navigation of these rivers.

The supposition is natural; but, anomalous as it may seem, the experience of the extensive irrigation of the plains of India and of Italy would seem to contradict it.

Captain Baird Smith,[18] in his "Italian Irrigation" says, pp. 171 and 172:

> I may mention here that the singular and interesting phenomenon of percolation, which is so marked in the beds of the Himalayan rivers of India, is not less strikingly shown in those of Northern Italy. In seasons of great dryness the entire volumes of the Ticino[19] and other irrigating rivers have at times been entirely exhausted to meet the demands of the cultivators. The results are thus adverted to by M. Lombardini, a minute and accurate observer, who has devoted himself especially to the study of river phenomena:
>
> "The subterranean water with which the plain is charged are also occasionally collected in the rivers, whose beds are below the level of the ground. These streams, exhausted in their upper portions by the channels of irrigation derived from them, are found to become gradually refilled at lower levels with new waters. The Ticino at Tornavento, the Adda at Cassano, and the Oglio at Torre Pallavicina,[20] in times of great dryness, are entirely closed and exhausted. Yet, without the aid of any visible affluent whatever, the streams soon re-appear, formed by new supplies derived from percolation through the banks and springs in the beds, so that they early again become navigable."
>
> This is precisely the result observed in Northern India, and with which the main objection urged against the

> grand Ganges Canal,[21] that it will ruin the navigation of the river, has hitherto been combated. I am glad to be able to bring Italian as well as Indian experience to the support of this work, besides which even the greatest of the Lombardian canals appear small.

In speaking of the effect of the canals on the navigation of the river Jumna in India,[22] the same author says, (Baird Smith, p. 386:)

> During four months it is occasionally necessary to abstract the entire visible stream for the supply of the canals, and for eight or ten miles below the bunds or embankments employed for the purpose, the bed is dry. Beyond this distance water appears; and by the time the river has reached the latitude of Saharunpur,[23] it has become a deep unfordable stream, with a considerable velocity of current. The explanation of this singular result, observed in greater or less degree in all streams which traverse the tract of country under the Siwalic Hills,[24] both east and west of the Ganges, is not difficult. From sections exposed by wells sunk in the vicinity of the Jumna, it is evident that the bed of the river is composed of a porous, readily permeable stratum of shingle resting upon clay or clay sand, which is comparatively impervious. The upper or shingle stratum is thoroughly saturated with water to a depth which, from sections we have observed, may be estimated at from 60 to 80 feet. The slope of the bed for the first ten miles from the lower hills is excessive, and there is consequently a considerable under-current through the shingle bed. The volume of the river may therefore be regarded as consisting of two separate parts: 1st. The visible stream, over the shingle bed; and, 2d, the invisible or under-stream through the shingle bed. The canal bunds affect only the former; and it is the latter which makes its appearance when, at the lower levels of the river's course, the sub-stratum of clay outcrops, and the porous shingle bed terminates. The under-current is thus thrown to the surface, and constitutes the main body of the river, and, with the additions it receives from affluents, is the volume available for navigation during the months of minimum supply.

From our observations, we believe that if a general system of irrigation of the San Joaquin, Tulare, and Sacramento Valleys is carried out, the effect of such irrigation will have very little influence on the navigation of the Sacramento and San Joaquin Rivers, which are the only navigable rivers in the Great Valley of California.

It should be observed that the quantity of water that will be used for the irrigation of the valleys mentioned above will be only a portion of the flow of these two rivers at and below the points at which they are now navigable; and of this portion a certain quantity will find its way back into the rivers again by percolation and underground drainage after it has done its work of irrigation. This will be particularly true of the San Joaquin River, where the greatest amount of irrigation is required.

This river is navigable for steamboats in its high stage only as high as the mouth of Fresno Slough, where the head-works of the San Joaquin and King's River Canal are located, and in its lowest stage only as high as Stockton Slough, which below the influence of the tides. Now, during its high stages when water is always abundant in the rivers flowing from the Sierra Nevada, the San Joaquin River receives the drainage of the whole Tulare Valley through Fresno Slough, a few miles below Watson's ferry.

The irrigation of the Great Valley above this point can therefore have very little influence on the navigation below it; for it is only the quantity of water which is taken up by the increased evaporation due to irrigation, and that going to form a component part of the increased vegetation of the country that is lost to navigation.

After once wetting the soil down to the water-bearing strata, all the remainder of the water of irrigation will be carried off by underground-drainage, and will find its way into the river at or above the point where winter-navigation ceases. Indeed, it may well be questioned whether the irrigation of the southern end of the Great Valley will not tend rather to improve than to injure the navigation of the river; for the water of irrigation will be held back during floods, when it is not wanted for navigation, and that portion of it which finds its way again into the river by underground-drainage will do so in a great measure when the river is falling, and at the time, therefore, when it is wanted for navigation.

In considering the effect of the abstraction of water for the irrigation of the San Joaquin Valley from that river, and from its tributaries below the mouth of Fresno Slough on the navigation of the river, we have on the west side the San Joaquin and King's River Canal, with a maximum discharge of 726 cubic feet per second, which is only about one-tenth the actual flow of the river at that point in the summer-season. It is said that the effect of this canal in lowering the water in the river has been tested by the experiment of closing the head-gates in the canal so as to exclude all water from the canal. The effect was to raise the water in the river below the head-works one inch and a half, from which we may conclude that the withdrawal of the quantity of water which the canal carries from the river lowers the water in the river one inch and a half.

To this extent, therefore, this canal may at certain stages of water injure its navigation.

The effect of canals of irrigation drawing their supply of water from the tributaries of the San Joaquin River on its eastern side, say from the right bank of the Upper San Joaquin River itself, from the Fresno, the Merced, the Tuolumne, and the Stanislaus, on the navigation of the river between Stockton and the head of high-water navigation, we believe will not be injurious, and, in fact, may be beneficial.

The effect of drawing water for irrigation from the tributaries of the San Joaquin below Stockton, from the Calaveras, the Mokelumne, and the Cosumnes can scarcely be felt on the navigation of the San Joaquin below that point, for here the depth of the water in the river is influenced by the ebb and flow of the tides.

The west side of the Sacramento Valley, as we have seen, must be irrigated by water drawn from the Sacramento River at, or a short distance below, Red Bluff,[25] and from Stony, Cache, and Puta Creeks.

The Sacramento River is navigable during the season of high water as far as Red Bluff; though since the consolidation of the railroad company with the California Steam Navigation Company it is rare that steamers are sent up the river higher than Princeton.[26]

During the low stage of water, Colusa[27] may be regarded as the head of navigation.

The effect of withdrawing a large quantity of water by a canal for irrigation, leaving the river in the vicinity of Red Bluff, would be to decrease the depth of water in the river at and immediately below that point.

At the time, however, when irrigation will be most needed--during the winter and spring--the river is always high, and the withdrawal of the quantity of water that will be required for irrigation would scarcely be felt.

During the late summer and early fall, when the river is low, but little water will be wanted for irrigation, and the withdrawal of what would be required could have but little effect on the navigation of the river at Colusa or Princeton, the head of navigation at that season of the year, for these places are one hundred miles by the river below the head of the proposed canal.

Of course, there will be a certain stage of the river when it is falling, and again when it is rising, when, without the withdrawal of any water from the river for irrigation, it would just be navigable for small steamers between Colusa and Red Bluff. If, at this stage, a large quantity of water be withdrawn from the river, the depth of water would be decreased, and the river would not be navigable.

How much the influence of such a canal on the navigation of the upper part of the river at these stages would not be felt, it will be impossible to state with certainty without knowing the discharge of the river at such times and the quantity of water that would be taken from it by the canal.

We may remark, however, that it is only the falling phase of the river that need be considered in this connection. In the months of July and August the river falls very slowly; and if it is just navigable at a certain stage, the withdrawal of a large quantity of water from it at that time might affect the navigation for some weeks; but in the fall, when the river rises, after the first rains, it rises suddenly, and the effect of the cause we are considering could only be felt for a few days, and generally for a few hours.

The effect of withdrawing a portion of the waters of Stony Creek for irrigation could have but little, if any, influence on the navigation of the river; for the greater portion of this water would find its way back again into the river above Princeton, which is the practical head of navigation, unless the river above be improved. And the appropriation of the waters of Cache and Puta Creeks to irrigating-purposes cannot affect the navigation of the river; for both of these streams find their escape into the river through Cache Slough, a tidal arm of the Lower Sacramento.

On the east side of the Sacramento River, between Red Bluff and the city of Sacramento, the principal tributaries are the Feather, the Yuba, Bear and American Rivers. Besides these rivers, there are numerous smaller streams, escaping from the foot-hills of the Sierra Nevada, and emptying into the Sacramento River above the mouth of the Feather, the largest of which are Butte and Chico Creeks, which are living streams all the year round, in the vicinity of the town of Chico.[28]

We do not think that the appropriation of all the water that will be wanted for the irrigation of the eastern side of the Sacramento will have any injurious effect on the navigation of that river, and for the reasons already stated in speaking of the tributaries of the San Joaquin on its eastern side.

On the whole, therefore, we conclude this subject by stating it as our belief that the irrigation of the Great Valley of California, in the manner we have sketched on our map, will have no injurious effect on the navigation of the San Joaquin and Sacramento Rivers except for a short time, at a certain stage of their waters, and for a short distance below the points where the proposed canals leave them, viz, the mouth of Fresno Slough on the San Joaquin, and Red Bluff on the Sacramento. Even here we do not think that the injury to navigation will be at all serious.

The canals for irrigation on the western side of the valley, owing to the necessity of giving them a gentle slope, may easily be made navigable. The San Joaquin and King's River Canal as far as constructed is navigable, and its continuation as projected will furnish a more certain and cheap navigation than that of the Upper San Joaquin River.

A canal from the Sacramento River, leaving it at Red Bluff, on its western side, may readily be made navigable. Thus, these two navigable canals would afford compensation to any supposed or real injury they might do to the navigation of the rivers.

When we reflect that no canal for navigation could be proposed in this or any part of the United States without the possible or supposed injury of some railroad, and, in fact, that no great public work of any kind can be carried into execution without injuriously affecting some existing interests, we think, if a comprehensive scheme for the irrigation of the Great Valley of California is ever undertaken, the effect of such irrigation on the navigation of its rivers may be disregarded.

WHAT IS IRRIGATION?

It may be well to state here, in general terms, in what the works of irrigation for these plains must consist; or, in other words, how the water is to be taken out of the rivers and spread over the land. This appears to us to be necessary to a proper comprehension of the subject, because the irrigation of the land has been practiced but very little by the farmers of the United States. With the exception of rice-culture along the sea-coast of a few of the Southern States, agricultural irrigation may be said to be almost unknown in this country.

Even in California it is yet in its infancy, although it was practiced for many years in some places by the old Spaniards particularly in the southern portion of the State.

The profession of the hydraulic engineer for agricultural purposes is almost unknown, and the farmers, as a general thing, do not understand how to use the water when it is delivered alongside their lands.

We have noticed that in some of the new canals which have been built, many mistakes as to their alignment and slope have been committed. In fact, the very first principles of hydraulic engineering, as applicable to agriculture, have been violated.

This is particularly the case in relation to the canals, or irrigating-ditches, at Visalia and Bakersfield. The irrigating-ditches at these places have too great a slope. The consequence is that the banks are washed away and the bottoms of the ditches scoured out, so that the water cannot be elevated sufficiently in many places to flow over the surface of the land which was intended to be irrigated.

Again, no attention, apparently, has been paid to drainage. The consequence is that the surplus water of irrigation, and that which escapes at low places through the banks of the ditches and sloughs, settles in pools in the lowest ground, becomes stagnant, and, under the influence of a sun which may be called tropical, renders the vicinity of these two towns unhealthful in the summer-season.

A main canal for irrigation must be taken from a river or lake. The quantity of land to be irrigated, the nature of the soil, the minimum rain-fall on this land during the year, and the kind of cultivation, or the amount of water which the land will require in a given period, are the elements which determine the size of the canal or the quantity of water it must deliver in a given time.

The first thing to be done is to raise the surface of the water in the river to such a height as will enable it to flow out through a canal on to the plain to be irrigated at the least possible expense. This is usually done by a dam across the river, though sometimes water can be taken from a river without a dam. The dams, as a general thing, will not require to be built to the full height of the banks of the rivers, but only high enough to command the highest land to be irrigated.

The canal will then be carried from the water above the dam, through the river-bank, in more or less deep cutting, on to the irrigable land.

These works, by which the water is taken from the river out to the land to be irrigated and its quantity regulated, are usually called "The head-works of the canal." It would be useless to enter into a detailed description concerning them, because they will differ in every river.

In looking over the "head-works" of the canals for irrigation in India and in Italy, we find great numbers of these works, but no two of them alike.

The size and slope of the main canals will depend on the quantity of water which they must carry in a given time, and the tenacity of the soil forming their bottoms and sides.

Perhaps the easiest way of showing how the land in these plains should be irrigated will be by an example. But it must be understood that these examples, in practice, will be of almost infinite variety, and it is only by understanding the principles upon which the canals and ditches must be laid out and constructed that a proper system of irrigation can be successfully introduced.

Let it be borne in mind that the object to be accomplished is, at any given time, to put from two to four inches of water on the soil, and hold it there until it is absorbed; say, one irrigation in the fall of the year, to enable the land to be plowed and the grain to be sowed; and three or four irrigations in the winter and spring, depending in number and quantity on the kind of cultivation and the amount of rain-fall during that time.

In order to show in the clearest manner in what the works for spreading the water from a main canal over the land usually consist, we have taken a case from the actual practice of the San Joaquin and King's River Canal Company, in which a portion of the land represented is prepared for the irrigation of wheat or barley, and the remaining portion for grass-pasturage. The system is shown on the sheet herewith, marked A.

The main canal has a grade of 1 foot per mile, and the ground slopes from the canal toward the lowest depression of the valley, which in this case is the San Joaquin River, about 8 feet per mile. The slope is shown on the sketch by dotted contour-lines for each foot of elevation.

Water is not taken directly from the main canal to the ground to be irrigated. It is first drawn from the main canal into a series of smaller canals, called "primary ditches." These primary ditches leave the main canal where the slope of the ground is favorable, in a direction more or less at right angles to its course. They follow the highest part of the land to be irrigated.

The distance apart of these primary ditches will vary according to the circumstances of the ground. In the example we are considering this distance is one mile.

The section of these primary ditches, like that of the main canal, is usually made partly in excavation and partly in embankment. In the example before us, however, these primary ditches are entirely in embankment, the water running on the natural surface of the ground, the earth to form the embankment being taken from outside the ditch. As a general rule, the water should not be taken from them directly to the ground to be irrigated. They are feeders drawing the water from the main canal and distributing it through a series of secondary ditches of smaller size, in which the water is on the surface of the ground, and retained in a given channel by banks of earth from 1 to 2 feet high. It is from these secondary ditches that the water is drawn off into the plow-furrows, and distributed on to and over the land to be irrigated.

It will be noticed that in the example of practical irrigation shown on our map, the contour-lines show that the ground slopes in nearly a true plane away from the main canal at the rate of about 8 feet to the mile. We have seen how the water is first delivered from the main canal into primary ditches, running down this slope at distances of one mile apart, and how this water is again distributed from the primary into secondary ditches, located one quarter of a mile apart, and running parallel to each other, with a slope of from 4 to 5 feet per mile; each of the secondary ditches is to irrigate the land between it and the next one below it. This piece of land in the example is eighty acres. We have now to show how the water is actually applied to the ground. For the sake of clearness we will confine our attention for the moment to the eighty acres shaded on the map, shown also in the sketch annexed marked B. The secondary ditch, marked AB, is to irrigate these eighty acres.

This land is first divided by plow-furrows parallel with the primary ditches and placed 40 yards apart. These are shown at 1-2, 3-4, 5-6, &c., up to 39-40. It is again divided by plow-furrows, called "checks," laid out parallel to the secondary ditch AB, at distances of fifty yards apart, measured along the line parallel with the secondary ditch. These are shown at 41-42, 43-44, up to 53-54.

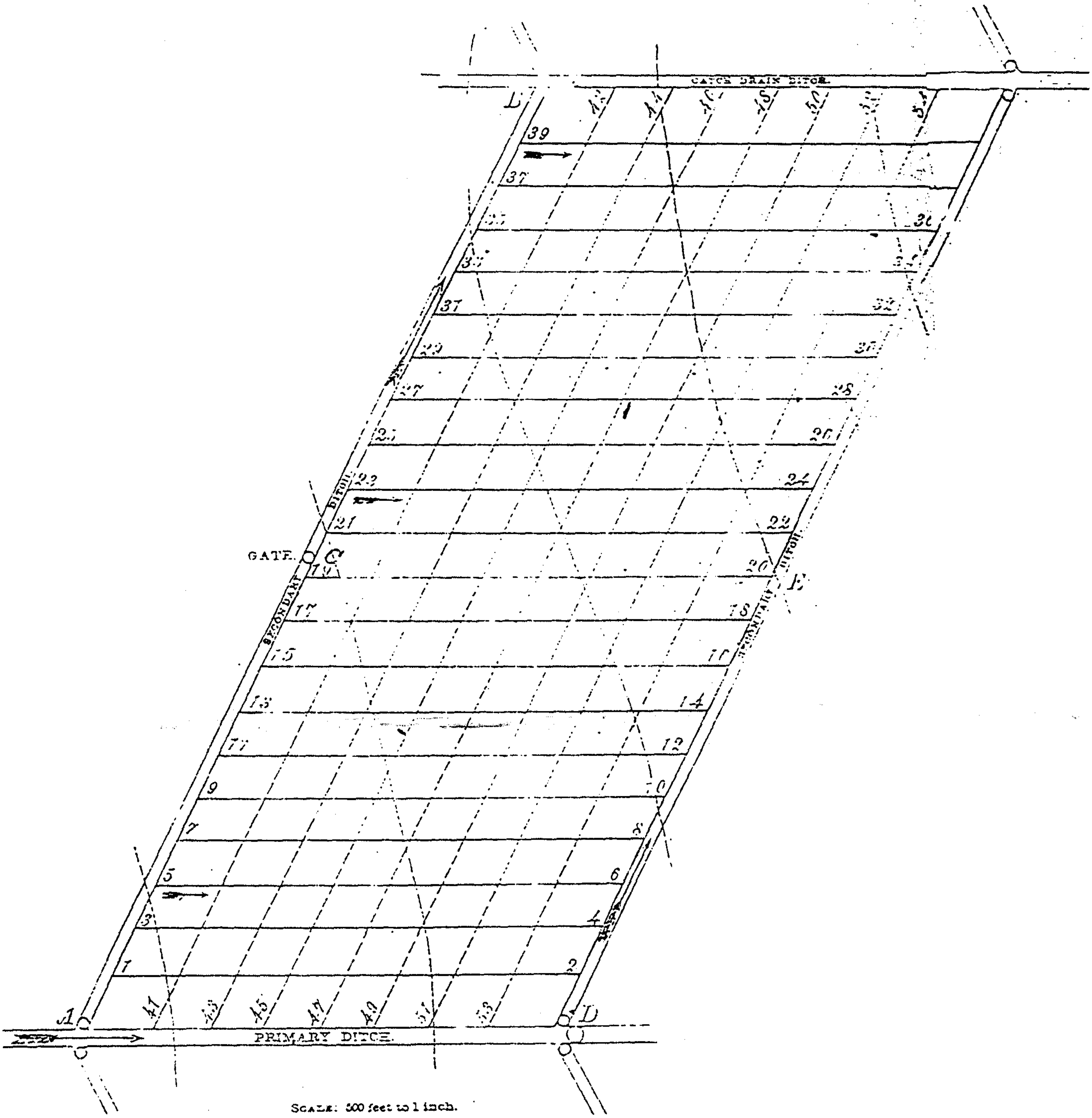
The note on the drawing marked A shows that each secondary ditch has a capacity sufficient to fill ten of the little boxes leading from it at 1, 3, 5, 7, &c., into the plow furrows.

To irrigate this land, then, we first close the gate at C in the middle of the secondary ditch AB, and open the gate at A, which communicates with the primary ditch, then the water will flow into the secondary ditch from A to C. Open the little gates at 1, 3, 5, 7, &c., and it will escape into the plow-furrows and run down to the first check-furrow, 41 41 1/2, where its flow will be checked, and it will gradually flow over the belt of land between AC and 41 41 1/2. This little belt can then be irrigated to any depth that may be required. When this is done, the plow-furrows at the intersection with the first check at 1 2, 3 4, &c., with 41 42, are opened with a hoe, and the water will then run down on to the next belt, included between 41 41 1/2 and 43 43 1/2, and so the process is continued until the forty acres included in the parallelogram ACDE has all been irrigated.

Now, if the gate at C be opened and those at 1, 3, 5, 7, &c., be closed, the water will flow into the lower part of the secondary ditch from C to B; and if the gates at 21, 23, &c., be opened, the other forty acres, CBFE, can be irrigated in the same manner.

As the ground slopes away from the secondary ditches and the parallel check-furrows at the rate of 8 feet to the mile, and as these checks are fifty yards apart, the slope between the adjacent checks will be 2.7 inches. When the water has backed up on the upper side of any given check-furrow to the depth of 2.7 inches, it follows that the ground on the lower side of the next check-furrow above will just be covered, and when it is 4 inches deep on the upper side of the lower check it will be only 1.3 inches deep on the lower side of the upper check. This does not give an entirely equal distribution of the water, but in porous soils there is a system of compensation for this unequal distribution by the percolation of the water standing in the secondary ditches and check-furrows finding its way to the belts of land immediately below them.

Sketch B.



SCALE: 500 feet to 1 inch.

Thus, in the example we are considering, the water from the secondary ditch AB will irrigate the ground immediately below this ditch by percolation if the soil is porous, and the water on the upper side of the checks 41 42, 43 44, &c., will be absorbed and irrigate the soil immediately below them. Of course, where the soil is impervious to water, like clay or adobe, the check-furrows should be closer together, in order to insure a more equal irrigation.

In the example of irrigation for alfalfa or permanent pasturage, the little furrow-channels are multiplied, insuring a more equal distribution of water.

The water which is not absorbed by the ground is carried off by the catch-drains and utilized for irrigating lands at a lower level.

This whole system of the distribution of water on to the land, as illustrated in our sketch, is in accordance with the principles which the experience of European countries as well as of India has established.

It should not be forgotten, however, that the quantity of water, as well as the details of its distribution, will vary acccording to the kind of cultivation. As the cultivation of wheat will require a difference in the times and details of irrigation from that of alfalfa or other grasses, so the cultivation of Indian corn will differ from wheat, and sugar-cane would differ from either of the others. In fact, each product will require a difference in the method of distributing and a difference in the quantity of water for each irrigation.

EXISTING AND HYPOTHETICAL CANALS.

Although we have been enabled to lay down on our map, with some approach to accuracy, the canals for a comprehensive system of irrigation on the west side of the Great Valley of California, because we have had access to surveys which were made for that purpose, such is not the case on the eastern side of the valley. Here we have no detailed surveys of the country.

It is true there are several small canals and irrigating-ditches on the eastern side of the valley, some of which are completed and in operation; but, as a general thing, those canals have not been laid out on scientific principles; they have not been projected on a plan, so as to form a part of a comprehensive irrigation-system for this side of the valley, and the surveys of these canals, even if attainable, would furnish us with very little valuable information.

We may mention, among these small canals and irrigating-ditches, those at Bakersfield, where the water is taken from Kern River; the irrigation at Visalia, where the water is taken from Kaweah River; three small canals leading from King's River, now partially completed; the Chapman Canal, on the right bank of the San Joaquin River; and the Fresno Canal, on the left bank of the Fresno River, (both partially completed, and laid down on our map.) Of these, the Fresno Canal is the best.

Besides the foregoing, there are small systems of irrigation scattered at different points throughout the foot-hills, all the way from the Tuolumne River to the Feather, the water for irrigation being drawn from ditches that were originally constructed for mining-purposes.

Many of these ditches have been more or less abandoned for mining, and their water is now diverted to the irrigation of gardens, orchards, and vineyards, which betoken the permanent settlement and cultivation of these foot-hills.

It results from our lack of detailed topographical knowledge of the country on the eastern side of the Valley of California that we can now only sketch a hypothetical system of irrigating-canals on that side of the valley. This we have done on our map.

The location of the supposed canals are shown in broken red lines, and are laid down as near as may be in accordance with the principles heretofore mentioned in this report; that is, each main river has two canals, one on either bank, extending to the right and left just below the base of the foot-hills, until they meet similar canals from the adjacent rivers; the whole of them taken together forming, as it were, a main exterior canal of large size, extending from the Kern River, on the south, to the vicinity of Red Bluff on the east side of the Sacramento River. From these main exterior canals, hugging close to the foot-hills, the country below them and lying between them and the central lines of drainage of the Great Valley can be irrigated by branch-canals, which will be the service-canals for the distribution of water for irrigation. The branch-canals in their turn would have their system of primary and secondary ditches, as has been already explained.

The hypothetical system of exterior and branch canals for the eastern side of the valley shown on the map must be understood as being only hypothetical. Although we have examined all the rivers on the eastern side of the valley with great attention, we do not know that we have in any single case selected the proper point on any river from which a main exterior canal should leave it, and, of course, it follows that we do not know that we have laid down any canal in the position it ought to occupy.

No comprehensive system for the irrigation of this portion of the valley, nor in fact for the irrigation of any country, can be made without a complete instrumental survey made for that special purpose. Then, the proper location, size, and height of the dams across the different rivers and streams can be discovered; the alignment, size, and slope of the exterior and interior canals, as well as of distributing-ditches, determined, and the country divided into different irrigating-districts which would be more or less independent of each other.

Here it may be remarked that all such natural districts, because they are natural, cannot be altered by legislation, and their boundaries are independent of the artificial boundaries of a State, county, or township unless those boundaries follow the natural lines of drainage, or the divisions of drainage-areas into different water-sheds.

GENERAL CONSIDERATIONS.

THE IRRIGATION OF THE FOOT-HILLS, STORAGE-RESERVOIRS, MINING, RECLAMATION OF OVERFLOWED LANDS, ETC.

In the preceding discussion of this subject, we have confined ourselves entirely to the irrigation of the valleys mentioned in the act of

Congress. We have endeavored to show the necessity of their irrigation, and some of the results that will flow from it.

That these plains will be extensively irrigated in the future, we have no doubt. But the works for a complete system of irrigation will be enormous and the cost too great for the present day.

A large increase of population in these valleys will be necessary before such works can be perfected. Time will bring this about, but probably fifty years will be necessary to complete it.

It is all-important that the works should be properly planned and located in the beginning, so that whatever is done to meet the present requirements of a sparse population may form a part of those that will be necessary to meet the demands of a population of millions by simply enlarging them.

Canals that may eventually cost $15,000 per mile need not at first cost more than $5,000 per mile, but they should be located on the right ground and so planned and built as to admit of enlargement without shifting the banks.

The works required, even at the present time, will be extensive and costly, and unity of action is absolutely necessary to their proper execution. If the Government of the United States lends any aid toward the accomplishment of this great scheme of irrigation, it should do so in full accord with the government of the State of California; and whatever action the State government may take in the matter should be taken in the interests of the people of the State, or otherwise the scheme of irrigation will be a failure.

Some authority must be exercised, in the first instance, in planning and locating any proper system for comprehensive irrigation. If left to themselves, the farmers in any country of large extent can never devise or execute such a system.

Constant conflicts would take place among them about the rights of water. The streams ought not to be left to the exclusive control of those living on their banks.

The main canal in many places will be miles away from where the water is most required; and if the location and construction of such canal and the distribution ditches be left to many different proprietors to carry out, each anxious for his own interests, and those interests in conflict or in apparent conflict with each other, and there be no authority to control their action, it is manifest that the system of irrigation will be begun in confusion and will end in financial disaster.

In future the foot-hills, particularly the foot-hills of the Sierra Nevada range, will also call for irrigation. In fact, as we have before stated, they are already irrigated in many places by water from mining-ditches.

The plains will furnish the large farms, but the homes of the well-to-do farmers will be found in the foot-hills or mountains. Their more healthful climate, more varied and picturesque scenery, finer fruits, and greater facilities of obtaining building-materials, as well as wood and water, mark them as places for the farmer's permanent home, and then they too will call for irrigation. This will be an irrigation different from that of the plains. The water will come from the Sierra Nevada Mountains. Large storage-reservoirs will then be constructed in the gorges and valleys of the mountains, and water will be brought down from them in ditches, pipes, and flumes, as water for hydraulic mining is now carried to the mines.

This system of irrigation for the foot-hills will doubtless be combined with obtaining water for mining those extensive gravel deposits of gold, which are yet almost untouched for want of water at sufficient elevation to work them profitably; many of which deposits could not be exhausted in a hundred years.

As the gold production of these mines will be immense, we may suppose that in the future the works for supplying them with water and for irrigating the foot-hills will be in like proportion.

The western flank of the Sierra Nevada will be dotted with reservoirs like some portions of India. Their water will first be used for mining-purposes, where it will be as valuable as for irrigation. Afterward it will be used for watering the foot-hills, and the waste water finally carried into the canals leading from the different rivers built for watering the plains.

We are aware that we are not called upon by the strict letter of our instructions to mention these considerations, and we allude to them only to show that in a complete and comprehensive consideration of the subject of irrigation in California they should not be forgotten.

And there is one other view of the subject which should be stated: we allude to the reclamation of the overflowed and swamp lands in the San Joaquin, Tulare, and Sacramento Valleys. Extensive irrigation will assist in their reclamation, for the water of irrigation, and particularly that stored for future use, will be held back during floods, when these lands are liable to damage, and will escape by percolation or be let into the rivers again through artificial channels after the floods are over, when it can do no injury.

It has been well said that "water is the wealth of California." If it has been so in the past, we believe it will be still more so in the future.

If the people of this State can be once convinced that the irrigation of the plains will be extended in time to the foot-hills, and their irrigation will be combined with the development of new and extensive mining-enterprises; that all irrigation will assist in the reclamation of more than one million acres of rich land, now almost valueless on account of being overflowed in wet winters; and that the water, after having been used for mining, will not be injured, but rather benefited for purposes of irrigation, we believe, after a complete system of irrigation is laid out for them, and proper laws and regulations in reference to the use and abuse of water established and enforced, that unity of action would be insured, and the people would take hold of the subject of irrigation with a will, and carry it out, except perhaps in particular instances, without much aid from Government.

But it is the duty of the Government to teach the value of irrigation, and lay out a comprehensive system, and enforce proper laws on the subject.

CHAPTER IV.

History, description, and statistics of irrigation in foreign countries.

Introductory remarks: Authorities--Irrigation in India; its necessity--Famines--Extent of proposed works--Price of labor--Description of Ganges Canal--Other canals in the Punjab and in the northwest provinces--Delta-systems of Southern India--Other canals in India--Tanks; their numbers and dimensions--Mudduk Masoor tank--Mode of construction --Inundation-canals--Wells--Superiority of channel-irrigation--Improvements by the English--Silt--Velocity of canals--Drainage; its relation to health--Measuring water; its necessity in California--Navigation of canals--Primary ditches--Administration of canals in India.
Statistics: Of Western Jumna Canal--Of Bari Doab Canal--Of other irrigation-canals in the Punjab--Of inundation-canals from the Sutlej and Indus Rivers--Of the Ganges Canal--Of Eastern Jumna Canal--Of Dhoon Canals.
General remarks: Financial aspect--Cost of maintenance; of repairs.
Description and statistics: Of Delta-irrigation in Madras--The Cauvery Delta--The Kistna Delta--The Godavery Delta--Official report for 1873 --Financial statement--Prospects for the next five years--Private enterprises in India--Madras Irrigation Company; its agreement; embarassments--The East India Irrigation Company; agreement; failure --Opinions of governor-general of India and of home office.

In the rainless regions of Egypt and in some portions of India, irrigation and systematic agriculture are of the same age, the latter being quite impossible separate from the former. The present purpose does not require an inquiry into the date of its origin and the circumstances attending the introduction of irrigation in ancient times. It is sufficient on this point for us to know that it has been used for thousands of years, and that in some countries it has been continuously applied throughout their historic existence. The wide distribution and range of this mode of cultivation under the most diverse climatic conditions deserves to be referred to.

This range is almost as long and as wide as that of civilization itself. It embraces countries where the rain-fall is high and the mean temperature that of the temperate zone, and others where the temperature